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INTERNATIONAL SPACE STATION ALPHA USER PAYLOAD OPERATIONS CONCEPT

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ABSTRACT

International Space Station Alpha (ISSA) will accommodate a variety of user payloads investigating diverse scientific and technology disciplines on behalf of five international partners; Canada, Europe, Japan, Russia, and the United States. A combination of crew, automated systems, and ground operations teams will control payload operations that require complementary on-board and ground systems.

This paper presents the current planning for the ISSA U.S. user payload operations concept and the functional architecture supporting the concept. It describes various NASA payload operations facilities, their interfaces, user facility flight support, the payload planning system, the on-board and ground data management system, and payload operations crew and ground personnel training.

This paper summarizes the payload operations infrastructure and architecture developed at the Marshall Space Flight Center (MSFC) to prepare and conduct ISSA on-orbit payload operations from the Payload Operations Integration Center (POIC), and from various user operations locations. The authors pay particular attention to user data management, which includes interfaces with both the on-board data management system and the ground data system. Discussion covers the functional disciplines that define and support POIC payload operations: Planning, Operations Control, Data Management, and Training. The paper describes potential interfaces between users and the POIC disciplines, from the U.S. user perspective.

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1.0 USER PAYLOAD OPERATIONS

Figure 1-1 depicts the overall user payload operations environment and its relationship to the integration functions for ISSA [1]. Typically, users become interested and involved in many activities interspersed with the activities listed below as "payload operations." To the user, these other activities may have far more value than the listed "payload operations" activities. However, the authors associate these other activities with results of successful payload operaions. For the purposes of this paper, the term *payload operations* refers to activities required to:

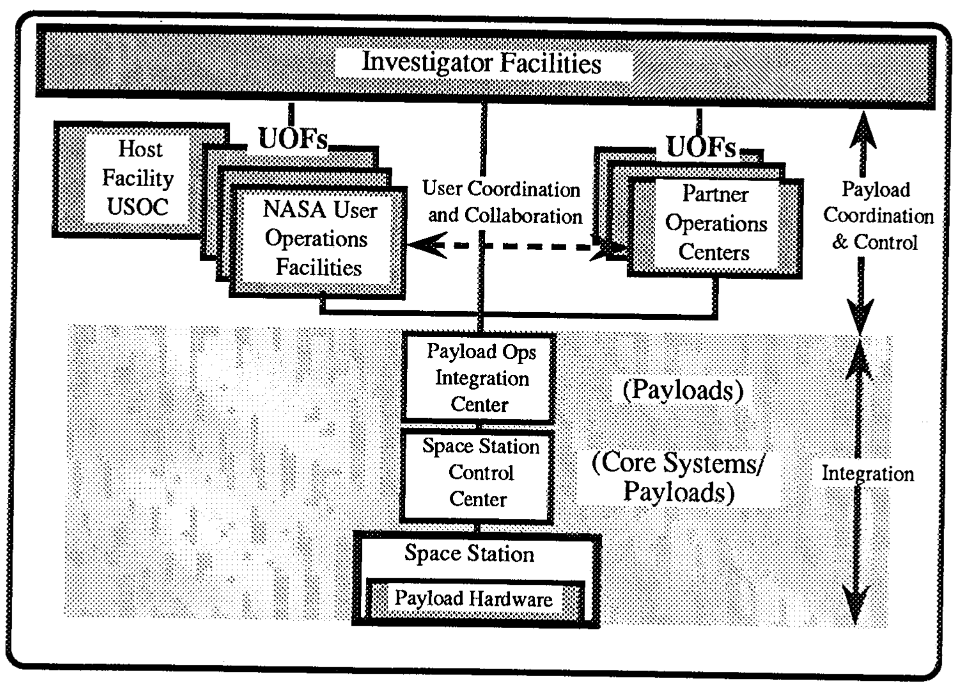

Figure 1-1. Overall Operations Concept

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- Plan/maintain equipment to perform its intended function
- Observe safety and equipment performance
- Monitor station resources required and/or consumed
- Analyze actual "on-orbit" performance versus objectives
- Adjust or alter equipment performance
- Manage data generation and collection
- Collect and preserve results
- Prepare equipment/samples for return to the ground

1. 1 FACILITIES AND INTERFACES

The following sections describe locations and some of the management interfaces involved in user payload operations. Users in all locations operate their payloads through the ISSA Payload Operations Integration Center (POIC). (Section 2)

1. 1. 1 User Operations Facilities

The NASA Office of Life and Microgravity Science and Applications, and the Office of Advanced Concepts and Technology, are considering development of facilities from which users may conduct payload and science operations. Initially, NASA will develop these User Operations Facilities (UOFs) to support and operate major on-board payload facilities that support more than one user. NASA will develop UOFs at Lewis Research Center, Cleveland, Ohio, for the fluids and combustion facility; Johnson Space Center (JSC), Houston, Texas for life science and biotechnology facilities; MSFC, Huntsville, Alabama for microgravity science facilities; Ames Research Center, Moffett Field, California, for non-human life sciences and the centrifuge facility [2]; and at Langley Research Center, Hampton, Virginia, for commercial and technology facilities. Figure 1-2 depicts the distributed user facilities infrastructure.

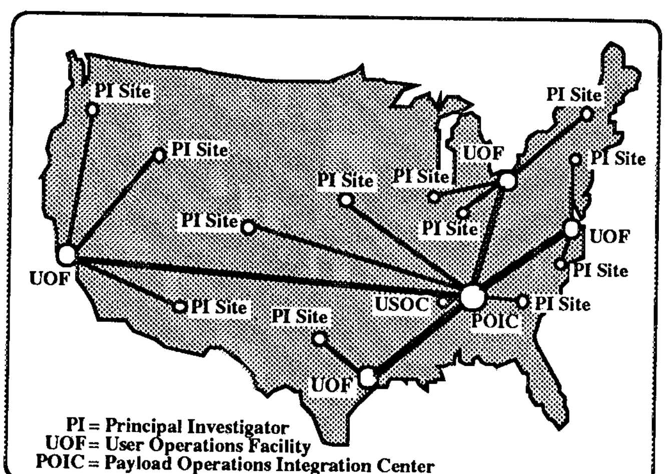

Figure 1-2. Distributed User Operations

1. 1. 2 United States Operations Center

The ISSA Program covers development of the United States Operations Center (USOC), collocated with the POIC in Huntsville, AL. This facility will provide floor space and operations consoles from which user teams may conduct payload operations. The ISSA Program took advantage of POIC development requirements in choosing both the location of the USOC and its processing and communications equipment.

To support the POIC, the ISSA Program developed capabilities to monitor payload health and status displays, process messages, command payloads, and conduct limited payload systems analyses. The program will make these capabilities available to USOC users and to UOF users who install compatible equipment, at no additional cost to the program. UOF developers have shown extreme interest in obtaining these capabilities.

At present, the only personnel the USOC may provide for user flight support will provide support for user data flow and data products, and for engineering support for the EXPRESS racks and pallets. EXPRESS stands for Expedite Processing of Experiments to Space Station. For payload operations, users will interface with the POIC either directly, or through *user-provided* operations integration teams within the USOC or UOF.

1. 1. 3 Remote User Facilities

Users may locate anywhere, from commercial facilities and university laboratories to NASA payload development centers. Some Space Station users desire to control laboratory experiments on-orbit from the user's home facility. If a user plans to control or execute real-time or "near real-time" activities defined in Section 1.0 as "payload operations" activities, from his home facility, the user should plan a constant interface with POIC, either directly or through a UOF. The POIC will require this interface to address safety concerns and assure that the payload's operation does not interfere with other payloads. No real technical obstacles exist to implementing operations from user home facilities, but users may incur some implementation costs.

Figure 1-3 [3] shows three remote payload operations scenarios, involving payloads of varying complexity and an experimenter operating from a remote home site .

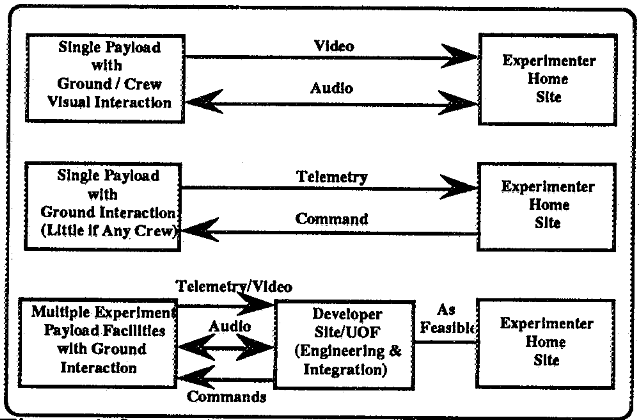

Figure 1-3. Payload Remote Operations Scenarios

1. 1. 4 Interfaces among U.S. User Facilities

Figure 1-4 [4] depicts interfaces users should consider in preparing for payload operations. Not all users will require all interfaces, but a careful check of each area will increase the effectiveness of payload operations planning.

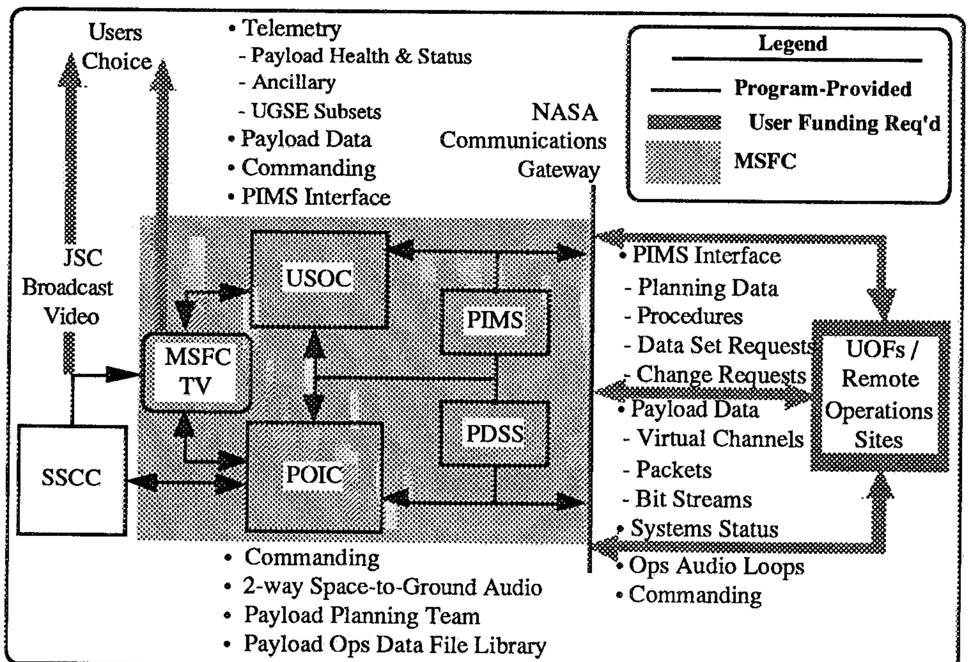

Figure 1-4. Potential User Interfaces

UOF-provided support should include:

- Planning information, procedures, change request interface
- Payload data interface
- Compliance with NASA Automated Information Security
- Payload Operations Personnel to interface with the POIC
- Training on UOF systems and capabilities as required
- Support for integrated training and simulations

1. 2 PAYLOAD PLANNING CONCEPT

The Payload Planning System (PPS) supports distributed planning concept [5]. Users may define their requirements to varying levels of detail, and according to the kind of planning center support available. The distributed planning concept recognizes both individual user planning and user-developed user planning centers. The concept includes centralized payload planning, probably within the POIC. Figure 1-5 depicts the planning concepts [6], and the following describes user involvement in distributed payload planning.

For *centralized planning*, users submit very detailed planning requirements to the POIC. The POIC will schedule payload activities and distribute the results for user review and analysis. Users will provide final detailed requirements based on the POIC-provided schedule. The POIC will prepare detailed schedules and generate payload planning products.

For *user windows*, the POIC distributes *envelopes* of time periods and station resources available to individual users. User requirements for flexibility in scheduling form the basis for these windows. The user window may accommodate a single payload activity, or a choice of activities. Users schedule operations within the window and prepare their detailed schedules

For *planning center envelopes*, the POIC distributes envelopes to user-developed user planning centers based upon planning center defined gross scheduling requirements. User planning centers may schedule payload operations activities for the users served. User Planning Centers may integrate the requirements of the users served, and produce a plan by which these users will operate. The POIC will make Payload Planning System software available to user planning centers at no additional cost to the program. To ensure crew safety and non-interference with other payloads, the POIC will review and approve user planning center envelope plans.

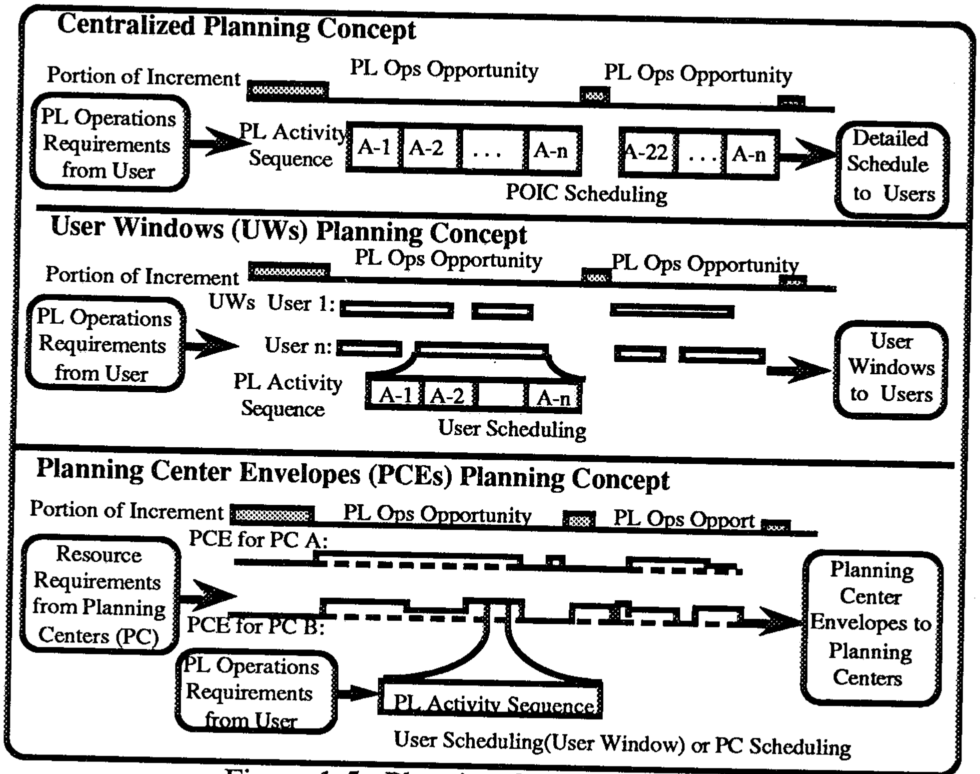

Figure 1-5. Planning Concepts

The POIC will integrate all user payload planning, regardless of where it was done, into a single integrated payload operations plan and provide this plan to the station systems planning center. The system planning center will incorporate the payload plan into an overall station operations plan. System and payload planners will resolve discrepancies and provide users with access to an agreed upon plan. Users will review and request changes to this plan through the Payload Information Management System (PIMS) interface.

1.3 ON-BOARD DATA SYSTEM CONCEPT

Designers refer to the ISSA data management system as the Command and Data Handling System. This system provides hardware and software computational resources to, (1) support ISSA core systems command and control; (2) support the payload users; and (3) provide services for flight crew and ground operations [7].

The Command and Control computers, implemented with Multiplexer / Demultiplexers (MDM) as the primary hardware device, constitute the highest tier of the architecture. They provide the point of control for subtier systems, payloads, and International modules. MDMs gather sensor and effector data through standardized analog and digital instrumentation interfaces and provide command and control of subtier elements through Mil-Std-1553B and RS-422 serial data buses. The Command and Control computer controls the Communication and Tracking subtier element equipment. This equipment provides the on-board audio and video, uplink and downlink, extra-vehicular, and orbiter communication [7].

Uplink and downlink communications use the Tracking and Data Relay Satellite System (TDRSS). The communications design implements uplink audio communication, and core systems downlink, with a single-fault-tolerant S-band communication system limited to 72 kbps for the uplink and 192 kbps for the downlink. The S-band system provides all command uplink and file transfer and all operations safety data downlink. The current design also provides a zero-fault-tolerant Ku-band communication system, limited to 50 Mbps to downlink payload telemetry. The Ku-band system downlinks all payload data and on-board video generated by the internal video systems. A communications outage recorder will capture data during communication outages with the ground. The POIC can schedule this data for playback or downlink at a future time. All communication to and from the ISSA will meet the Consultative Committee on Space Data Systems (CCSDS) telemetry standard.

The payload subtier element interfaces to the Communications and Tracking subtier element for use of uplink, downlink, and video services. The Payload MDM serves as the "command and control" computer for the Payload data architecture and point to point/bus communication media for payload data transfer. The payload subtier provides command/control media, high rate data communications media (<100 Mbps), medium rate data media (< 10 Mbps) and multiple rack-to-rack communications media (≤ 10 Mbps).

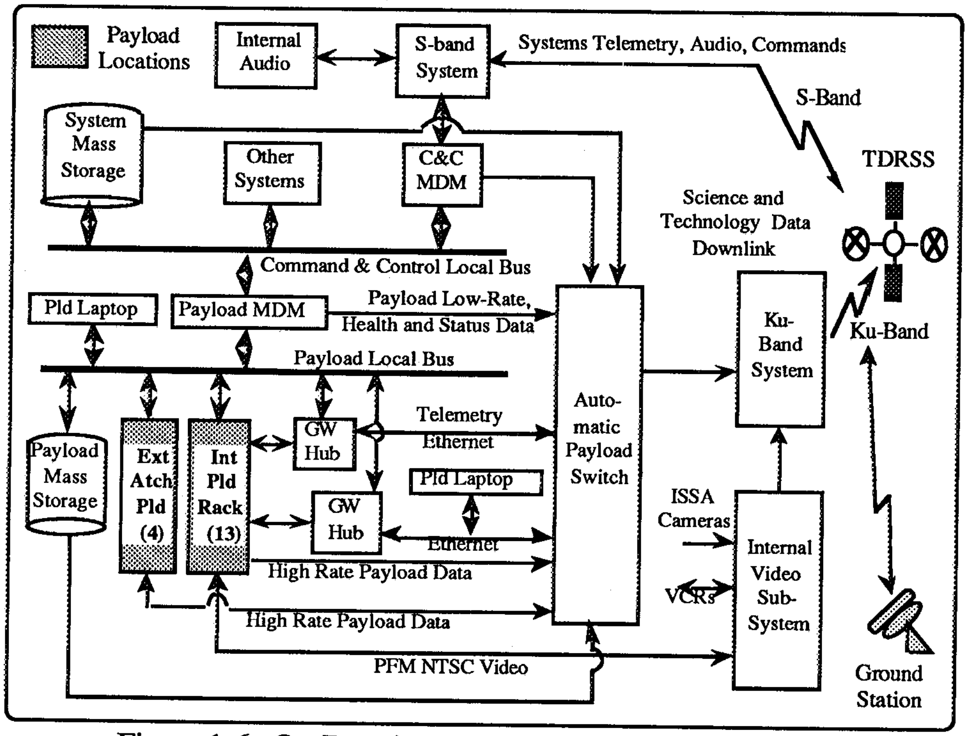

Figure 1-6. On-Board Data Architecture

An 802.3 payload ethernet routes medium rate payload telemetry data. Each payload rack has an ethernet interface controlled by a gateway/hub. The gateway/hub controls polling of the network and medium rate telemetry routing to the Ku-band downlink through the automated payload switch.

A separate ethernet (802.3) with its own gateway/hub, available at each rack, provides payload rack-to-rack communication, and payload portable computer data transfer where resource efficiency precludes using payload local buses. This ethernet can also be used for downlink, if required.

Figure 1-6 depicts the on-board data architecture. The payload MDMs (one primary and one cold backup) provide overall U.S. payload complement command/control and monitoring functions. They provide the interface with the Command and Control computers for resource allocation, passing of payload safety parameters and receipt of ground commands. The design configures payload MDMs as remote terminals on the Command and Control MDM 1553B bus. They serve as the bus controllers on each of the four (4) 1553B payload local buses. The payload MDMs have high rate data link interfaces to the automated payload switch which provides a path for downlink of health and status, ancillary, and low rate telemetry data to the Ku-band downlink.

Payload local buses, implemented with Mil-Std-1553B buses, provide command and control, data distribution, and limited low rate telemetry interface for U.S. payloads. These buses cover internal payload racks (one interface each for 13 locations) throughout the U.S. Laboratory and the external payload locations (one interface at each of 4 locations). The payload local buses provide the U.S. laboratory with portable computer ports, the primary crew interface to the payload network for payload management. The payload local buses recognize all payload locations and support devices as remote terminals

The automated payload switch / high rate data link system routes U.S. high rate payload data on board. Each payload rack and each attached location has two fiber optic serial digital interfaces (high rate links) with an automated payload switch. The automated payload switch provides optical switching of inputs to the High Rate Frame Multiplexer for downlink and can also switch inputs to other rack locations to accomplish rack-to-rack communication using the high rate data links.

Payloads use the ISSA internal video system to transmit pulse frequency modulated National Television Standards Committee standard video between payload racks, or to the Ku-band system for downlink.

As described above, the on-board data system provides a variety of interfaces to meet the diversity of requirements expected from payload users. Users will select the interface with the on-board data system that meets the user's overall data requirements. Table 1-1 summarizes the interfaces.

Table 1-1. P/L Data Requirements/Interfaces

Requirements/ Interface	Mil-Std-1553B	Telemetry Ethernet	R-to-R Laptop Ethernet	High Rate Links
Command and Control	X			
Laptop Support	X		X	
<1 Mbps telemetry	X	X		
<10 Mbps telemetry		X	X	X
<50 Mbps telemetry				X
Rack-to-Rack Comm			X	X

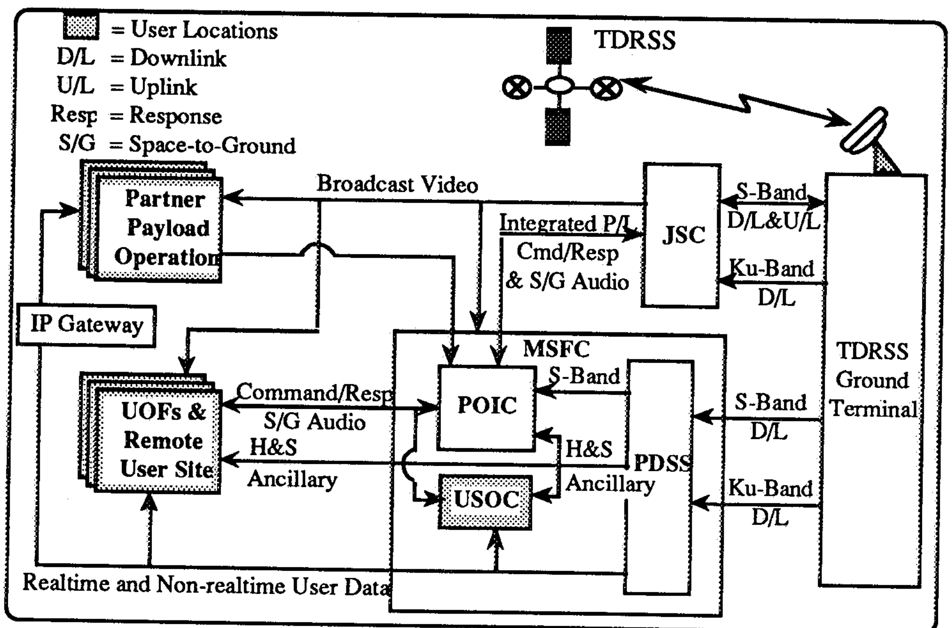

Figure 1-7. Ground Data Architecture

1.4 GROUND DATA SYSTEM CONCEPT.

Figure 1-7 shows the ground portion of the ISSA data system [8]. Telemetry in CCSDS format passes through the Tracking and Data Relay Satellite System (TDRSS). The TDRSS Ground Terminal simultaneously rebroadcasts received data to the Johnson Space Center (JSC) and to the Marshall Space Flight Center (MSFC), using a domestic satellite. JSC captures S-band data for systems operations, and strips video data from Ku-band to rebroadcast using existing NASA video networks. MSFC provides the primary distribution point for all payload data.

The Payload Data Services System (PDSS) [9] at MSFC receives the broadcast from the TDRSS Ground Terminal. PDSS ignores the video data in the Ku-band data stream and strips out the payload data to a Virtual Channel Data Unit format, a CCSDS packet format, or a Bitstream Protocol data unit format, depending on individual user requirements. PDSS distributes this payload data including health and status of the payloads, required ancillary data, and science and technology data to payload users as defined by previous agreements between the payload user and the ISSA program. The ISSA Program provides distribution to the United States Operations Center. The payload user having the specific distribution requirement will provide distribution from MSFC to the UOFs or any other remote site. Users can implement this requirement using existing NASA networks or may rent commercial networks. PDSS also receives S-band data and provides it along with pre-defined Ku-band data (e.g. payload health and status data) and required ancillary data to support the POIC.

The program will provide a common user interface to payload users located at a User Operations Facility or at a remote site, provided the facility has elected to fund and equip the required communication capability and has POIC-compatible workstations. This interface will provide payload users access to command shells, program databases, planning and procedures data input and output.

The POIC will distribute audio to payload users located at the USOC or at an appropriately equipped UOF or remote site. Audio will include required space-to-ground loops and ground-to-ground payload operations loops from the POIC. The facility hosts for the UOF or remote site will determine required internal facility audio loops.

Johnson Space Center will distribute downlinked video, using existing NASA networks, to the NASA Field Centers. Users not already equipped to receive this video need to identify their video requirements and negotiate for required support.

Because of advances in network technologies, the user has many affordable choices for interfaces to receive data from payloads on-board ISSA. Users will select the ground data system interface that meets the user's overall data requirements.

1. 4. 1 Payload User Database [4]

Payload users will provide information in response to Payload Analytical Integration activities during pre-increment definition. Payload user inputs gathered during this process will become part of a database which will provide a single controlled source from which the integration and operations elements may draw information.

During pre-increment activities, the POIC integration team will use the payload database to identify payload user command and telemetry requirements. Integrators will incorporate this information into a command and telemetry data base, accessible for execution through the POIC.

1. 4. 2 Telemetry

The ISSA Program manages and controls the on-board and ground data systems to support payload operations. This includes control of the on-board Command and Data Handling System, Communications and Tracking System operations, distribution, and ground data services supporting payload telemetry.

User responsibilities include submitting appropriate telemetry requirements during pre-increment integration planning for telemetry operations planning and performance.

1. 4. 3 Data Reduction and Analysis [4]

Payload user responsibilities include data reduction and analysis. PDSS processing includes only that processing necessary to deliver data to payload user facilities/locations in the form that the payload user input the data to the on-board data management system. PDSS time orders the data and removes redundant information. The POIC processes payload operations data such as health and status of payloads, ancillary, and limited station systems monitoring data. If payload users require payload data reduction and analysis for critical, time-sensitive operational decisions, they should use the most reliable and expeditious systems available. An "operations rule" to provide the POIC with default decisions if data does not become available in a timely manner, should accompany each decision for which the user needs to reduce or analyze data.

1. 4. 4 Data Archiving [4]

Payload user responsibilities include data archiving. PDSS does not intend their temporary "short term storage" to serve as an archive. The POIC does not plan to archive any of the payload operations data processed for the POIC. If payload users want to archive payload health, status, and safety data generated for the conduct of operations, users must record that data as part of a user data stream. Johnson Space Center will archive selected audio and video data generated to support payload operations, but the user should consider making required audio and video part of the user's archive.

2.0 PAYLOAD OPERATIONS INTEGRATION FUNCTIONAL DISCIPLINES

Space Station payload operations integration involves two major levels of responsibility. The first deals with *payload independent* functions primarily concerned with overall station management and mission success (e.g. station systems and crew safety). The Space Station Control Center at JSC controls this function.

The second integration level addresses *payload dependent* operations integration and payload operations success. The POIC executes this role and manages the payload complement in both planning and real-time command and control tasks. This function insures that the overall payload integrated plan operates within the constraints of available station resources and systems limitations. The POIC functional discipline teams listed below [10] work with user operations/facilities teams as described in the following sections:

- Payload Planning
- Operations Control
- Data Management Process
- Training

2. 1 PAYLOAD PLANNING

Payload planning consists of operations requirements definition, tactical planning, pre-increment planning, and execution planning. Planners require payload user interfaces during all planning phases.

Payload users provide parameters that define the payload operations requirements to support strategic and tactical payload utilization planning. These parameters provide a source of operations requirements for execution level payload planning. Payload users interface with the payload planners to ensure adequate interpretation of payload planning requirements.

The POIC will coordinate with the users for planning requirements. Based on user payload planning inputs, program guidelines, payload resource allocations, and resource availabilities from the Space Station Control Center, POIC payload planners develop an integrated payload plan. Users assess whether the operations plan satisfies their functional objectives, permits payload-to-payload output data correlation, and provides expected resource utilization. Users also assess whether their ground systems, facilities, and communications networks can support the proposed payload operations.

Following pre-increment planning users participate in execution level payload planning. This encompasses development of payload plans and products required to support and execute system and payload activities on-board and on the ground during a given period of the increment. In coordination with the Increment Payload Operations Planning Group, which will consist of all the users for a particular execution payload complement, users may submit planning or operations change requests which the POIC will use in developing execution planning products. User responsibilities include developing and updating procedures and on-board stored commands used as planning products to implement updated plans.

2. 2 OPERATIONS CONTROL

The operations control team executes the payload plan. When a station or payload contingency changes the plan, the operations control team assesses and alters the plan to continue safe operations until they can re-establish nominal operations. Operations control and support activities include monitoring payload health, safety, security, payload commanding, data flow, crew communications, payload procedures maintenance and coordination, and contingency and anomaly resolution support.

When anomalies interrupt planned operations, the POIC will coordinate options with the user operations facilities. Operations controllers will consult with the users and payload planners when real-time replanning involves short-term redistribution of space station resources.

All user operations facilities and the POIC monitor payload execution, and support the flight crew. Users update their respective payload commands and procedures as required. The POIC requires a user interface for contingency support as a result of either a payload, station system, or ground system anomaly. The POIC may need users to provide payload input to resolution and replan. The POIC will coordinate payload user requirements to communicate with the on-board crew.

2. 3 DATA MANAGEMENT PROCESS

The data management function responsibilities include coordination, integration, and control of the ISSA payload data systems as part of operations integration. The station data systems include the Command and Data Handling, and Communications and Tracking operations in support of payload data and video flow, and telemetry management including distribution and ground systems and services. Ground system requirements, video development, and data integration management teams perform this function. Payload data management planning personnel schedule and assess end-to-end data systems capabilities to support payload planners and operations control teams. This activity provides inputs to the planning process as it relates to end-to-end data systems, and schedules on-board Command and Data Handling, and Communications and Tracking utilization.

The POIC may require a single point of contact at each UOF to interface with the POIC Data Management Team for flight support data management functions. This point of contact will represent the UOF during "pre-pass briefings" (the periodic operations status briefings given by the Data Management Team to cover data activities), and during contingency and trouble-shooting activities within the data distribution system.

2. 4 TRAINING

ISSA training philosophy builds flight and ground crew unity by joint training and simulations on payload related activities. For payload-specific crew training, particularly on scientific or technological principles, Payload Development Centers or other specific user sites will do the training. The training concept promotes initial familiarization training and later detailed payload- specific training on the routine operation of each individual payload at user facilities, under user supervision.

User payload training responsibilities include flight crew and ground support personnel introductory and familiarization training. Investigators will provide crew operations training on individual experiments. The program will provide multiple experiment integrated training at the Payload Training Complex for integrated payload operations and skill maintenance training. The Payload Training Complex is part of the Space Station Verification and Training Facility which will provide a "whole station" environment to exercise station-wide systems/payload and ground/air operations in a series of simulations involving crew, users and ground controllers. Additional training of ground controllers constitutes an integral part of payload operations product development. Users participate throughout to ensure training meets user objectives.

The ISSA Program will insure adequate crew training to meet objectives set jointly with the users. Early discussions between users and payload integrators will define the level of fidelity of user-provided payload simulators and user involvement in individual crew training. Users should consider simulator and training requirements for both payload-specific training and integrated payload training.

User responsibilities include defining payload simulator requirements and providing simulators. User responsibilities may include providing instructors during individual payload training. Users will participate in simulations among operations and training elements.

3.0 SUMMARY

The operations approach developed by the ISSA program and its payload users consists of operations infrastructure and corresponding end-to-end data systems that will allow an effective means to produce quality science and technology results. Based on proven experience from Spacelab and other shuttle payload missions, this approach allows evolution to *highly distributed* operations for a variety of remote users in a variety of operations locations.

With the evolving changes in station flight system designs over the past few years, this concept has remained fundamentally constant. The current approach has the necessary foundation and *flexibility* to meet the expanding user operational needs into the next century. The system must adapt to changes in user requirements including experiment complexity, planning priorities, and physical operational location.

Implementing the most *user-friendly* concept possible, within the constraints of decreasing budgets, constitutes one of the future's biggest challenges for NASA and its international partners.

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